(12) **United States Patent**

Hofman et al.

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(54) **SYSTEM AND METHOD FOR CONTROLLING THE POSITION OF A ROBOT CARRIAGE BASED ON THE POSITION OF A MILKING STALL OF AN ADJACENT ROTARY MILKING PLATFORM**

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This patent is subject to a terminal disclaimer.

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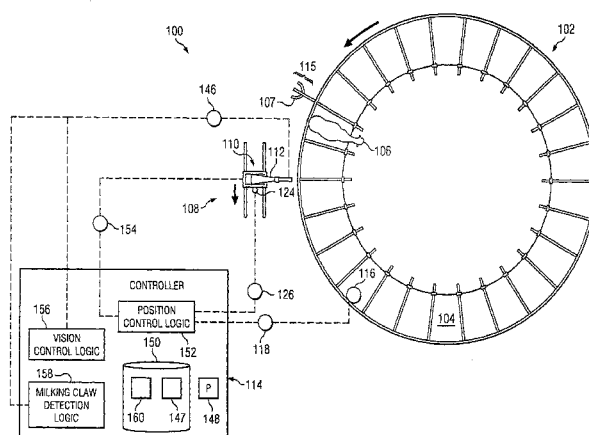
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(57) **ABSTRACT**

A system includes a carriage track positioned adjacent to a rotary milking platform, a robot carriage positioned on the carriage track such that the robot carriage may move along the carriage track, and a controller. The controller determines a movement of a milking stall of the rotary milking platform from a first rotational position to a second rotational position. The controller further determines a position of the robot carriage on the carriage track corresponding to the movement of the milking stall of the rotary milking platform. The controller also communicates a position signal to a carriage actuator coupled to the robot carriage and the carriage track. The position signal causes the carriage actuator to move the robot carriage along the carriage track to the determined position in conjunction with the movement of the rotary milking platform.

20 Claims, 10 Drawing Sheets

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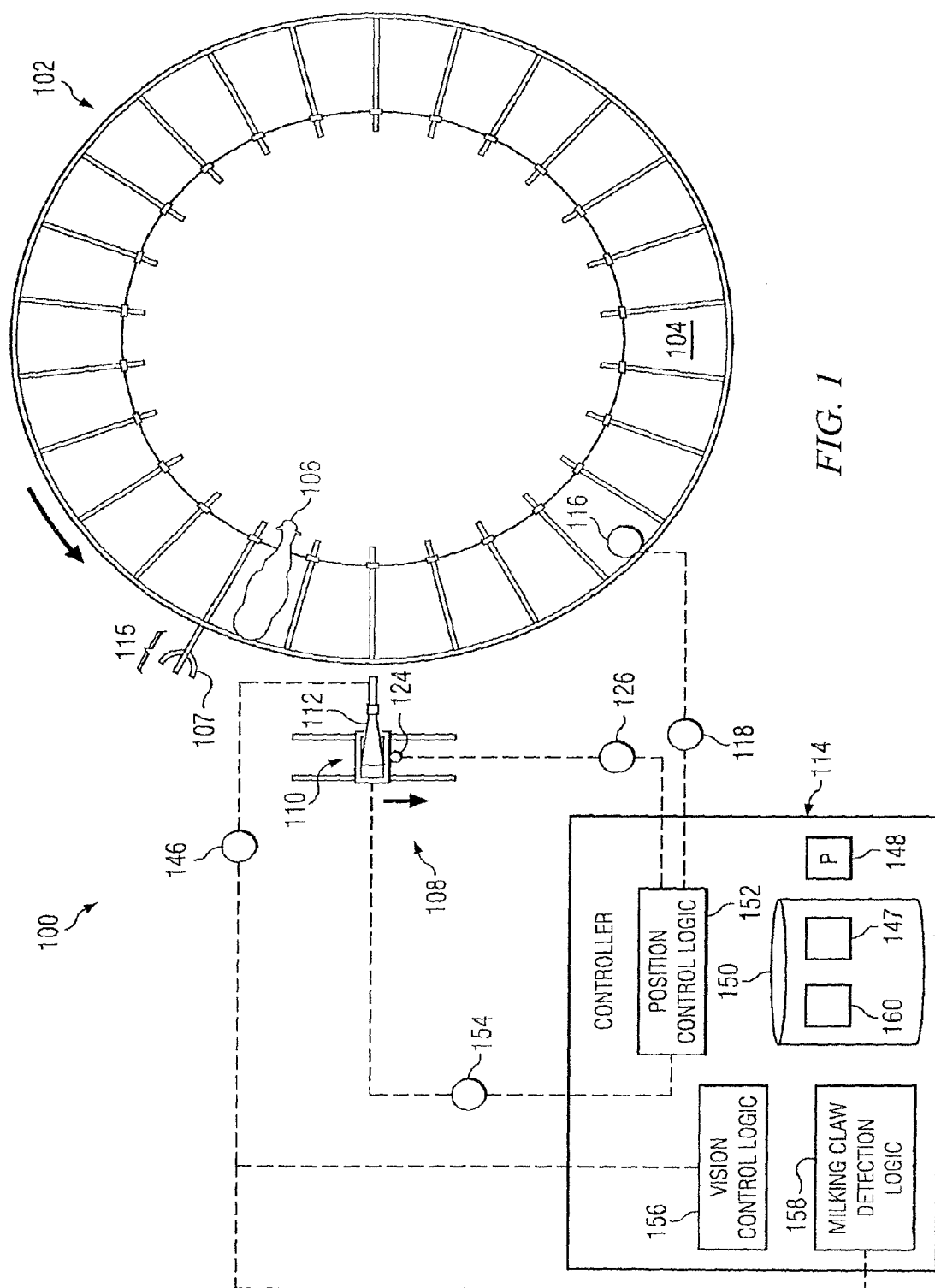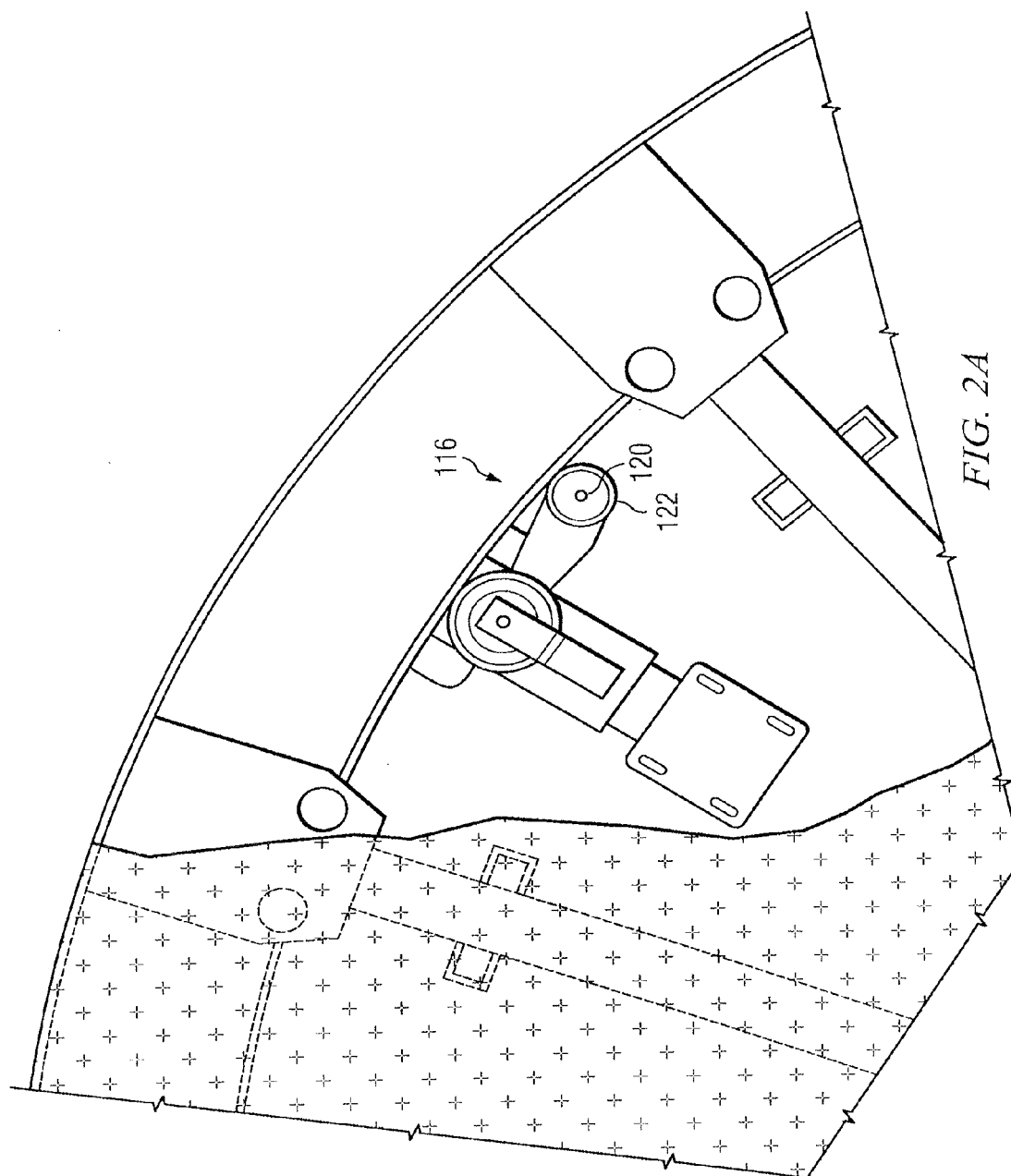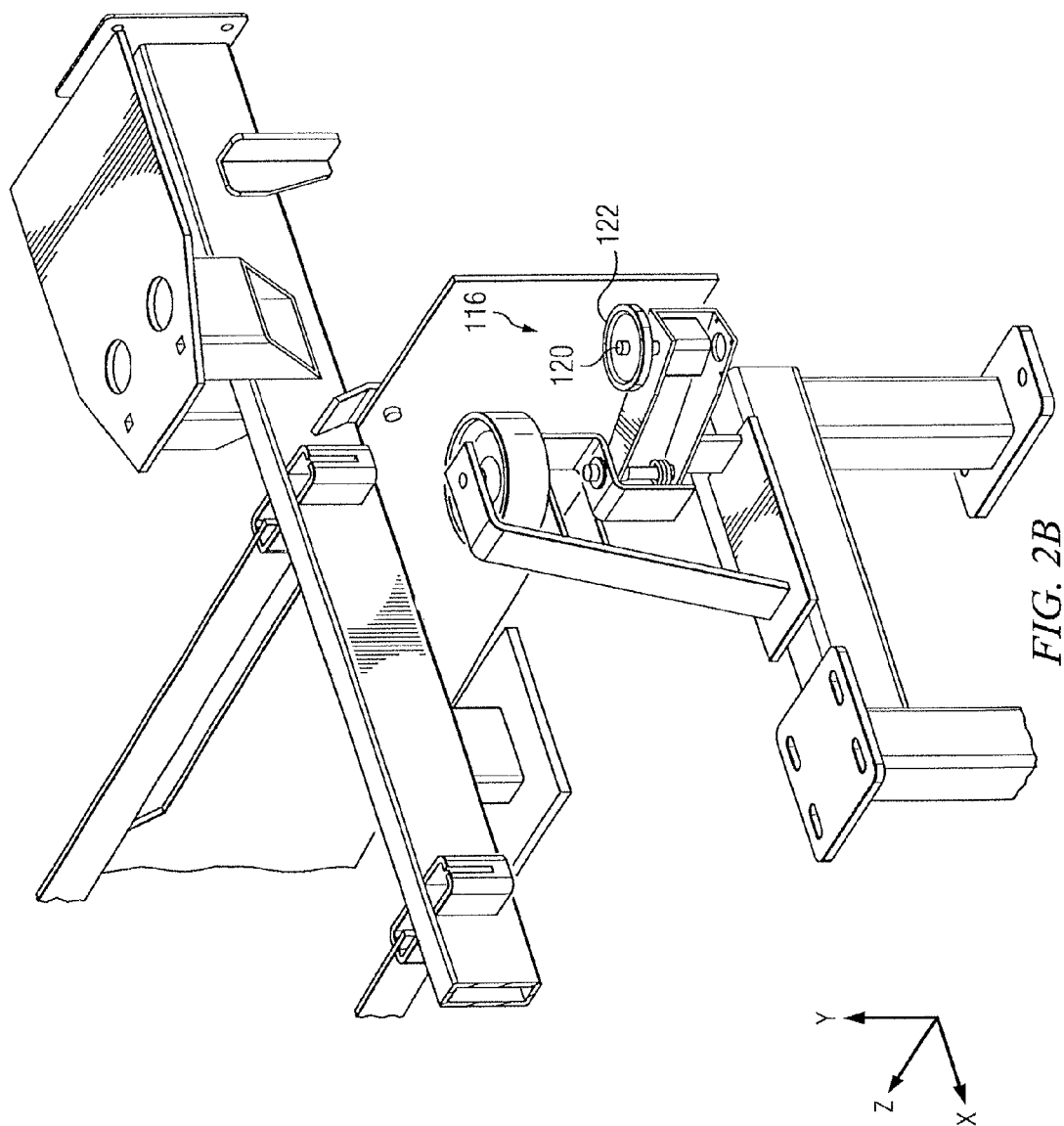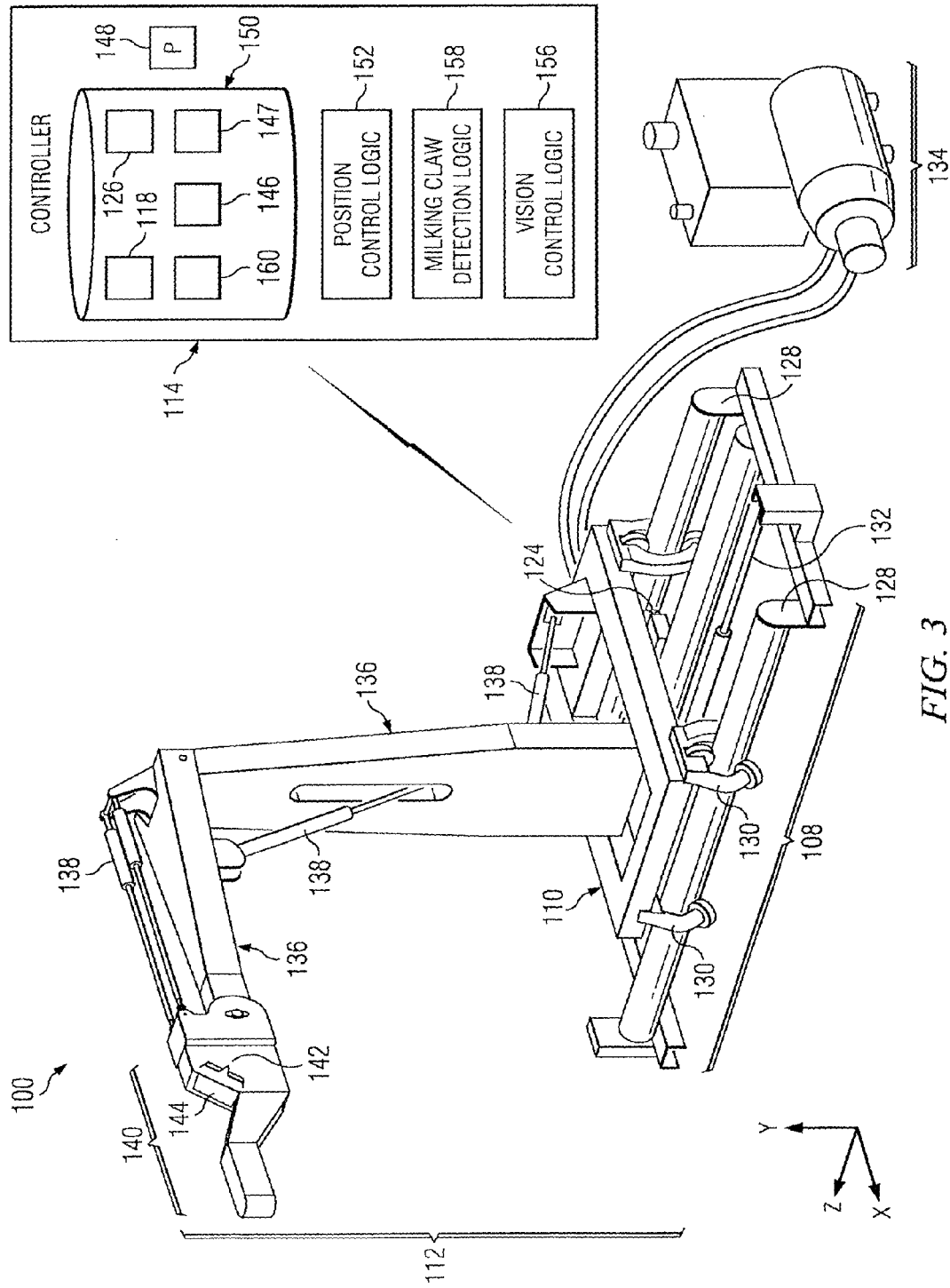
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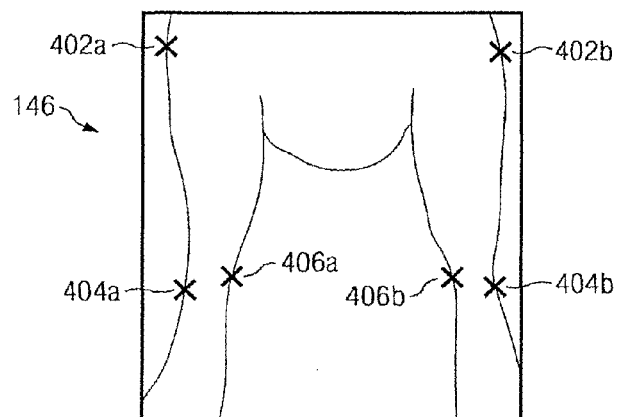
* cited by examiner

FIG. 1
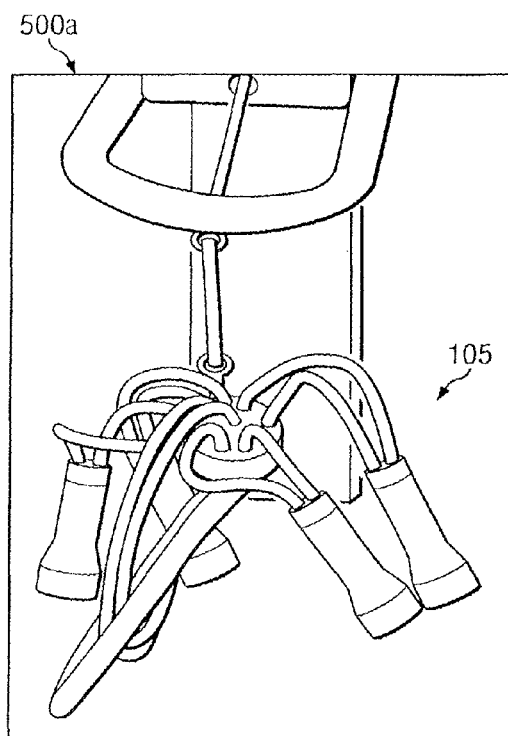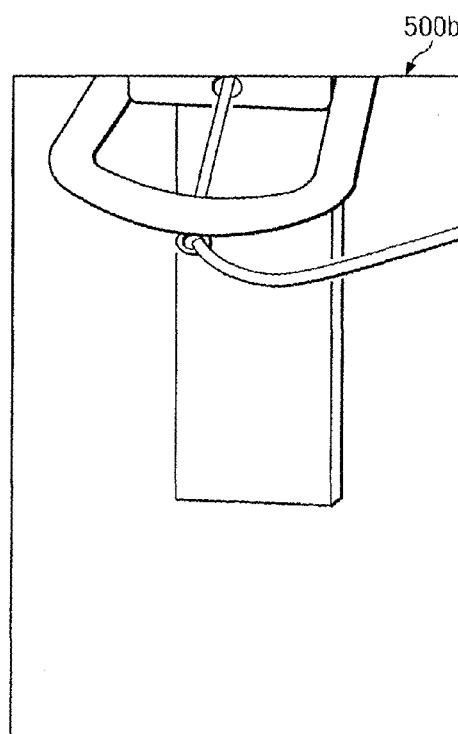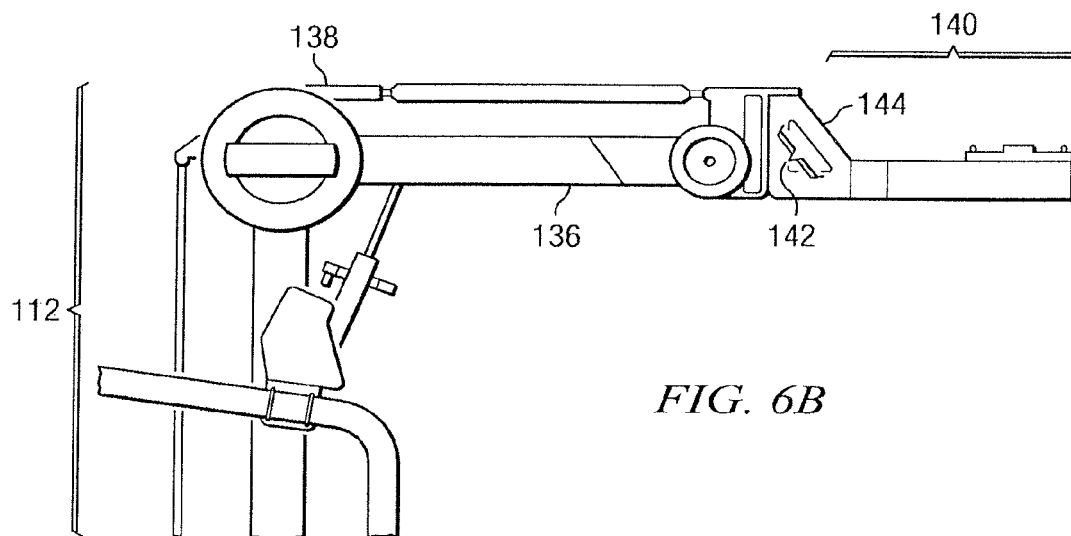
FIG. 2A

116

122

120

FIG. 2B

Y

Z

X

CONTROLLER

148

P

150

126
118
160

147
146

POSITION
CONTROL LOGIC
152

MILKING CLAW
DETECTION LOGIC
158

VISION
CONTROL LOGIC
156

114

124

136

138

138

138

136

142

144

140

100

112

128

128

132

130

130

130

110

108

134

Y
Z
X

FIG. 3

402a — ✕   ✕ — 402b

146 —

404a — ✕   ✕ — 406a   406b   ✕   ✕ — 404b

FIG. 4

500a —

105 —

FIG. 5A

500b —

FIG. 5B

FIG. 6A

FIG. 6B

FIG. 7

800

802 — (START)

804 — RECEIVE A FIRST ROTARY ENCODER SIGNAL INDICATING A FIRST ROTATIONAL POSITION OF A MILKING STALL OF A ROTARY MILKING PLATFORM, THE FIRST ROTATIONAL POSITION CORRESPONDING TO A STARTING LINEAR POSITION OF A ROBOT CARRIAGE ON A CARRIAGE TRACK POSITIONED ADJACENT TO THE ROTARY MILKING PLATFORM

806 — RECEIVE A SECOND ROTARY ENCODER SIGNAL INDICATING A SECOND ROTATIONAL POSITION OF THE MILKING STALL OF THE ROTARY MILKING PLATFORM

808 — DETERMINE, BASED ON A DIFFERENCE BETWEEN THE SECONDARY ROTARY ENCODER SIGNAL AND THE FIRST ROTARY ENCODER SIGNAL, A DESIRED LINEAR POSITION OF THE ROBOT CARRIAGE ON THE CARRIAGE TRACK, THE DESIRED LINEAR POSITION BEING A POSITION CORRESPONDING TO THE SECOND ROTATIONAL POSITION OF THE MILKING STALL OF THE ROTARY MILKING PLATFORM

810 — COMMUNICATING A POSITION SIGNAL TO A CARRIAGE ACTUATOR COUPLED TO THE ROBOT CARRIAGE AND THE CARRIAGE TRACK, THE POSITION SIGNAL CAUSING THE CARRIAGE ACTUATOR TO MOVE THE ROBOT CARRIAGE ALONG THE CARRIAGE TRACK TO THE DESIRED LINEAR POSITION

812 — RECEIVE AN ABSOLUTE ENCODER SIGNAL CORRESPONDING TO AN ACTUAL LINEAR POSITION OF THE ROBOT CARRIAGE ON THE CARRIAGE TRACK

814 — DETERMINING A POSITION ERROR BASED ON A COMPARISON OF THE ACTUAL LINEAR POSITION OF THE ROBOT CARRIAGE AND THE DESIRED LINEAR POSITION OF THE ROBOT CARRIAGE

816 — POSITION ERROR EXCEED THRESHOLD VALUE?   NO

YES

818 — (STOP ROTARY)   *FIG. 8*

START

900 — COMPARE PIXELS OF UPPER OUTER AREA OF IMAGE

904 SOME PIXELS CLOSER THAN OTHERS? —NO

YES

908 — ASSOCIATE LOCATION WITH A HIP OF THE DAIRY LIVESTOCK

912 — COMPARE PIXELS OF LOWER OUTER AREA OF IMAGE

916 SOME PIXELS CLOSER THAN OTHERS? —NO

YES

920 — ASSOCIATE LOCATION WITH AN OUTER EDGE OF HIND LEG

924 — COMPARE PIXELS OF LOWER INNER AREA OF IMAGE

SOME PIXELS CLOSER THAN OTHERS? —NO
928

YES

932 — ASSOCIATE LOCATION WITH AN INNER EDGE OF HIND LEG

936 ENOUGH DATA POINTS ? —NO

YES

940 ARE HIND LEGS FAR ENOUGH APART? —NO

YES

944

944 — INSTRUCT ARM TO APPROACH UDDER

END

FIG. 9

1000

START — 1002

1004
RECEIVED TRIGGER INDICATING MILKING STALL IS ADJACENT TO ROBOT ARM ?

NO

YES

1006
IS MILKING CLAW ATTACHED TO TEATS OF DAIRY COW ?

YES

1008
ALLOW MILKING STALL TO ROTATE BY WITHOUT EXTENDING ROBOTIC ARM

NO

1010
ARE HIND LEGS FAR ENOUGH APART ?

NO

YES

EXTEND ROBOTIC ARM BETWEEN HIND LEGS OF DAIRY COW — 1012

PERFORM DESIRED OPERATION — 1014

RETRACT ROBOTIC ARM FROM BETWEEN LEGS OF DAIRY COW — 1016

END — 1018

FIG. 10

SYSTEM AND METHOD FOR CONTROLLING THE POSITION OF A ROBOT CARRIAGE BASED ON THE POSITION OF A MILKING STALL OF AN ADJACENT ROTARY MILKING PLATFORM

RELATED APPLICATIONS

This application is a continuation of U.S. Ser. No. 14/329,399, filed Jul. 11, 2014 entitled "System and Method for Controlling the Position of a Robot Carriage Based on the Position of Milking Stall of an Adjacent Rotary Milking Platform" which is a continuation of Ser. No. 13/448,897, filed Apr. 17, 2012, which is now U.S. Pat. No. 8,800,487 issued Aug. 12, 2014, which is a continuation-in-part application of U.S. patent application Ser. No. 13/095,963 entitled "Automated System for Applying Disinfectant to the Teats of Dairy Livestock", filed Apr. 28, 2011, which is now U.S. Pat. No. 8,707,905 issued Apr. 29, 2014, which claims the benefit under 35 U.S.C. §119(e) of the priority of U.S. Provisional Application Ser. No. 61/378,871 entitled "Automated System for Applying Disinfectant to the Teats of Dairy Livestock", filed Aug. 31, 2010.

TECHNICAL FIELD

This invention relates generally to dairy farming and more particularly to a system and method for controlling the position of a robot carriage based on the position of a milking stall of an adjacent rotary milking platform.

BACKGROUND

Over time, the size and complexity of dairy milking operations has increased. Accordingly, the need for efficient and scalable systems and methods that support dairy milking operations has also increased. Systems and methods supporting dairy milking operations, however, have proven inadequate in various respects.

SUMMARY

According to embodiments of the present disclosure, disadvantages and problems associated with previous systems supporting dairy milking operations may be reduced or eliminated.

In certain embodiments, a system includes a carriage track positioned adjacent to a rotary milking platform, a robot carriage mounted to the carriage track such that the robot carriage may move linearly along the carriage track, and a controller. The controller is operable to receive both a first rotary encoder signal indicating a first rotational position of a milking stall of the rotary milking platform (a position corresponding to a starting linear position of the robot carriage on the carriage track) and a second rotary encoder signal indicating a second rotational position of the milking stall of the rotary milking platform. The controller is further operable to determine, based on a difference between the second rotary encoder signal and the first rotary encoder signal, a desired linear position of the robot carriage on the carriage track, the desired linear position being a position corresponding to the second rotational position of the milking stall of the rotary milking platform. The controller is further operable to communicate a position signal to a carriage actuator coupled to the robot carriage and the carriage track, the position signal causing the carriage actuator to move the robot carriage along the carriage track to the desired linear position.

In certain embodiments, a method includes receiving both a first rotary encoder signal indicating a first rotational position of a milking stall of a rotary milking platform (a position corresponding to a starting linear position of a robot carriage on an adjacent carriage track) and a second rotary encoder signal indicating a second rotational position of the milking stall of the rotary milking platform. The method further includes determining, based on a difference between the second rotary encoder signal and the first rotary encoder signal, a desired linear position of the robot carriage on the carriage track, the desired linear position being a position corresponding to the second rotational position of the milking stall of the rotary milking platform. The method further includes communicating a position signal to a carriage actuator coupled to the robot carriage and the carriage track, the position signal causing the carriage actuator to move the robot carriage along the carriage track to the desired linear position.

Particular embodiments of the present disclosure may provide one or more technical advantages. For example, certain embodiments of the present disclosure may provide a system that allows a robot carriage mounted on a linear carriage track to accurately track the movement of a milking stall of an adjacent rotary milking platform. Because the robot carriage may carry an automated system for performing one or more functions associated with the milking of a dairy livestock located in the milking stall of the rotary milking platform (e.g., a robotic arm for applying disinfectant to the teats of the dairy livestock and/or attaching a milking claw to the teats of the dairy livestock), certain embodiments of the present disclosure may facilitate a reduction in the need for human labor to perform certain functions associated with milking dairy livestock using a rotary milking platform. As a result, certain embodiments of the present disclosure may reduce the cost associated with certain dairy milking operations. In addition, the automation facilitated by certain embodiments of the present disclosure may increase the throughput of the rotary milking platform, thereby increasing the overall milk production of the rotary milking platform.

Certain embodiments of the present disclosure may include some, all, or none of the above advantages. One or more other technical advantages may be readily apparent to those skilled in the art from the figures, descriptions, and claims included herein.

BRIEF DESCRIPTION OF THE DRAWINGS

To provide a more complete understanding of the present invention and the features and advantages thereof, reference is made to the following description taken in conjunction with the accompanying drawings, in which:

FIG. 1 illustrates an example rotary milking system, according to certain embodiments of the present disclosure;

FIG. 2A-2B illustrate top and perspective views of an example rotary encoder of the system depicted in FIG. 1, according to certain embodiments of the present disclosure;

FIG. 3 illustrates a detailed view of an example track, robot carriage, and robot arm of the system depicted in FIG. 1, according to certain embodiments of the present disclosure;

FIG. **4** illustrates an example image signal identifying located edges in depth corresponding to the edges of the hind legs of a dairy cow, according to certain embodiments of the present disclosure;

FIGS. **5A-5B** illustrate example image signals corresponding to an example storage location of a milking claw in the system depicted in FIG. **1**, according to certain embodiments of the present disclosure.

FIGS. **6A-6B** illustrate example positions of a robot arm for the generation of an image signal, according to certain embodiments of the present disclosure;

FIG. **7** illustrates an alternative example rotary milking system, according to certain embodiments of the present disclosure;

FIG. **8** illustrates an example method for controlling the position of a robot carriage based on the position of a milking stall of an adjacent rotary milking platform, according to certain embodiments of the present disclosure;

FIG. **9** illustrates an example method for analyzing an image signal to determine if the hind legs of a dairy cow are spaced far enough apart to allow for extension of a robotic arm, according to certain embodiments of the present disclosure; and

FIG. **10** illustrates an example method for determining whether to operate a robot in conjunction with a rotary milking platform based on detection of a milking claw, according to certain embodiments of the present disclosure.

DETAILED DESCRIPTION

FIG. **1** illustrates an example rotary milking system **100**, according to certain embodiments of the present disclosure. System **100** includes a rotary milking platform **102** having a number of stalls **104** each configured to hold a dairy cow **106**. In order to facilitate the milking of a dairy cow **106**, each stall **104** may have an associated milking claw **107** configured for attachment to the teats of the dairy cow **106** located in the milking stall **104**. System **100** further includes a track **108** and a robot carriage **110** carrying a robot arm **112**, robot carriage **110** being mounted on track **108** such that robot carriage **110** is able to translate laterally along track **108**. System **100** further includes a controller **114** operable to control the movement of robot carriage **110** along track **108** and/or the movement of the robot arm **112** mounted to robot carriage **110**.

In certain embodiments, rotary milking system **100** may facilitate the performance of one or more operations associated with the milking of a dairy cow **106** located in a milking stall **104** of rotary milking platform **102**. As particular examples, rotary milking system **100** may facilitate (1) the cleaning and/or stimulation of the teats of a dairy cow **106** prior to the attachment of teat cups of a milking claw to the teats of the dairy cow **106** (e.g., using a preparation tool of robot arm **112**), (2) the attachment of the teat cups of the milking claw **107** to the teats of a dairy cow **106** (e.g., using a teat cup attacher of robot arm **112**), and/or (3) the application of disinfectant to the teats of a dairy cow **106** (e.g., using a spray tool of robot arm **112**).

In association with the performance of one or more of the above-described operations associated with the milking of a dairy cow **106**, controller **114** may perform a number of functions. First, controller **114** may control the movement of robot carriage **110** along track **108** such that robot carriage **110** moves along track **108** at a rate corresponding to the rotational speed of rotary milking platform **102**. As a result, one or more of the above-described operations may be performed while rotary milking platform **102** is in motion.

Second, controller **114** may determine whether enough space exists between the legs of a dairy cow **106** (e.g., based on image signal(s) **146** generated by vision system **142**, as described in detail below) to allow a portion of robot arm **112** to extend between the legs and perform one or more of the above-described operations. Third, controller **114** may confirm that the milking claw is detached from the teats of the dairy cow **106** prior to causing a portion of robot arm **112** to extend between the legs of the dairy cow **106** (as one or more of the above-described operations may be performed subsequent to milking of the dairy cow **106**).

Although a particular implementation of system **100** is illustrated and primarily described, the present disclosure contemplates any suitable implementation of system **100**, according to particular needs. Additionally, although the present disclosure is described with regard to the milking of dairy cows **106**, the present disclosure contemplates that system **100** may be applicable to the milking of any suitable dairy livestock (e.g., cows, goats, sheep, water buffalo, etc.).

Rotary milking platform **102** may include any suitable combination of structure and materials forming a platform with a number of stalls **104** positioned around the perimeter such that the stalls **104** rotate about a center point as dairy cows **106** in stalls **104** are milked. In the depicted embodiment, milking stalls **104** are arranged in a side-by-side configuration such that a dairy cow **106** in a milking stall **104** faces the middle of rotary milking platform **102**. In this configuration, robot arm **112** may extend and retract from between the hind legs of a dairy cow **106** in order to perform one or more operations associated with the milking of the dairy cow **106**. Each milking stall may **104** may have an associated milking claw **107** configured for attachment to the teats of a dairy cow **106** in order to facilitate the milking of a dairy cows **106** in the milking stall **104**. The milking claw **107** may be stored at a storage location **115** in or adjacent to the associated milking stall **104** when the milking claw is not is use (i.e., when it is not attached to the teats of a dairy cow **106**).

Although a rotary milking platform **102** having a particular configuration, size, and number of stalls **104** is illustrated, the present disclosure contemplates a rotary milking platform **102** having any suitable configuration, size, and number of stalls **104**, according to particular needs. For example, in one alternative configuration, milking stalls **104** of rotary milking platform **102** may be arranged in a herringbone configuration (where the milking stalls **104** are oriented on a bias relative to the perimeter of milking platform **102**). In this configuration, robot arm **112** may extend and retract from the side of the dairy cow **106** (i.e., between a front leg and a hind leg of a dairy cow **106**) in order to perform one or more operations associated with the milking of the dairy cow **106**. In another alternative configuration, milking stalls **104** of rotary milking platform **102** may be arranged in a tandem configuration (where the front of a dairy cow **106** in a first milking stall **104** is facing the rear of a dairy cow **106** in an adjacent milking stall **104**), and robot arm **112** may extend and retract from the side of the dairy cow **106** (i.e. between a front leg and a hind leg).

In certain embodiments, a rotary encoder **116** may be configured to generate rotary encoder signals **118** corresponding to the rotational position and/or speed of rotary milking platform **102**. As illustrated in detail in FIGS. **2A-2B**, rotary encoder **116** may be positioned relative to rotary milking platform **102** such that a rotary encoder wheel **120** contacts at least a portion of rotary milking platform **102**. Rotary encoder wheel **120** may contact any suitable portion of rotary milking platform **102** such that rotation of

rotary milking platform **102** causes rotation of rotary encoder wheel **120**. For example, rotary encoder wheel **120** may contact an inner (or outer) portion of a circular band located beneath the floor of stalls **104** near the outer edge of rotary milking platform **102**.

In certain embodiments, rotary encoder **116** may comprise any suitable electro-mechanical device operable to convert an angular position of a shaft **122** into an electrical signal comprising a number of pulses (i.e., rotary encoder signals **118**). Because the number of pulses generated by rotary encoder **116** per revolution of rotary milking platform **102** may be known (e.g., 1000 pulses), the pulse count generated by rotary encoder **116** at any given time may correspond to the rotational position of rotary milking platform **102**. Similarly, the frequency of pulses of generated by rotary encoder **116** may correspond to the rotational speed of rotary milking platform **102**.

Returning to FIG. **1**, track **108** may be positioned adjacent to rotary milking platform **102** and may include any suitable combination of structure and materials facilitating the attachment of robot carriage **110** thereto such that robot carriage **110** may move along track **108** adjacent to a rotary milking platform **102**. In one embodiment, track **108** comprises straight rails positioned parallel to one another and the robot carriage translates laterally along track **108** tangent to rotary milking platform **102**. In another embodiment, track **108** may comprise curved rails. Movement of carriage **110** tangent to rotary milking platform **102** may allow the robot arm **112** riding on carriage **110** to track the movement of a dairy cow **106** located in a milking stall **104** of the rotary milking platform **102**. As a result, the robot arm **112** may perform one or more automated functions associated with the milking of the dairy cow **106**. For example, the robot arm **112** may comprise a spray tool for applying disinfectant to the teats of the dairy cow **106**. As another example, the robot arm **112** may comprise a preparation tool for cleaning and/or stimulating the teats of the dairy cow **106** prior to the attachment of the teat cups of a milking claw **107**. As yet another example, the robot arm **112** may comprise teat cup attacher for attaching the teat cups of milking claw **107** to the teats of the dairy cow **106**. Although system **100** is primarily described as being used in conjunction with milking stalls **104** of a rotary milking platform **102** throughout the remainder of this description, the present disclosure contemplates system **100** being used in conjunction with any suitable type of milking stall, according to particular needs.

In certain embodiments, an absolute encoder **124** may be coupled to robot carriage **110** and may be configured to generate absolute encoder signals **126** corresponding to the linear position and/or speed of robot carriage **110** on track **108**. For example, absolute encoder **124** may have a structure and operation similar to rotary encoder **116** (discussed above). Because absolute encoder **124** may generate a known number of pulses per distance (e.g., meter) traveled by robot carriage **110**, the count of pulses generated by absolute encoder **124** at any given time may correspond to the linear position of robot carriage **110** on track **108**. Similarly, the frequency of pulses generated by absolute encoder **124** may correspond to the linear speed of robot carriage **110** relative to track **108**.

FIG. **3** illustrates a detailed view of an example track **108**, robot carriage **110**, and robot arm **112** of system **100**. In the illustrated example, track **108** includes one or more tubular track members **128** each corresponding to one or more rollers **130** of robot carriage **110**. Rollers **130** of robot carriage **110** may roll along track members **128**, permitting robot carriage **110** to translate laterally along track **108**. In

certain embodiments, a carriage actuator **132** may be attached to both track **108** and robot carriage **110** such that extension/retraction of carriage actuator **132** causes movement of robot carriage **110** along track **108**. The extension/retraction of carriage actuator **132** may be governed by an actuator drive mechanism **134**, which may include a hydraulic pump, a pneumatic pump, or any other suitable drive mechanism operable to cause extension/retraction of carriage actuator **132**.

In certain embodiments, the robot arm **112** riding on robot carriage **110** may include a number of arm members **136** pivotally attached to one another. Robot arm **112** may additionally include a number of arm actuators **138** each operable to extend and retract in order to cause movement of robot arm **112**. The extension/retraction of arm actuators **138** may be governed by actuator drive mechanism **134**, described above. Robot arm **112** may additionally include a tool attachment **140** operable to perform one or more functions associated with the milking of a dairy cow **106**. For example, tool attachment **140** may comprise a spray head operable to apply disinfectant to the teats of a dairy cow **106**. As another example, tool attachment **140** may comprise a preparation tool for cleaning and/or stimulating the teats of the dairy cow **106** prior to the attachment of the teat cups of a milking claw **107**. As yet another example, tool attachment **140** may comprise a teat cup attacher operable to attach the teat cups of a milking claw **107** to the teats of a dairy cow **106**.

In certain embodiments, tool attachment **140** may include a vision system **142** housing a camera **144**. Camera **144** may include any suitable camera operable to generate one or more image signals **146** corresponding to all or a portion of a milking stall **104** and/or all or a portion of a dairy cow **106** located in the milking stall **104**. In some embodiments, camera **144** may be operable to generate still images at particular points in time. In other embodiments, camera **144** may be operable to generate a continuous video image signal. As one particular example, camera **144** may be a three-dimensional camera operable to generate a three-dimensional video image signal **146** corresponding to the rear of a dairy cow **106**.

As described in further detail below, image signals **146** generated by vision system **142** (1) may be used by controller **114** (e.g., using vision control logic **156**, described below) to position all or a portion of robot arm **112** relative to a dairy cow **106** such that tool attachment **140** may perform one or more of the above-described functions (e.g., by determining whether enough space exists between the hind legs of the dairy cow **106** to allow the extension of at least a portion of robot arm **112** between the hind legs), and/or (2) may be used by controller **114** (e.g., using milking claw detection logic **158**, described below) to determine whether a milking claw **107** is attached to the teats of dairy cow **106** in milking stall **104** (as it may be desirable to confirm that the milking claw **107** is not attached to the teats of the dairy cow **106** before robot arm **112** performs certain functions associated with the milking of dairy cow **106**).

Although track **108**, robot carriage **110**, robot arm **112**, and tool attachment **140** are depicted as having a particular configuration, the present disclosure contemplates these components having any suitable configuration, according to particular needs. Furthermore, although robot arm **112** is depicted as having a particular number of members **136** having a particular structure, the present disclosure contemplates any suitable number of members **136**, each having any suitable structure, according to particular needs. Moreover, although robot arm **112** is depicted as having a particular

tool attachment **140**, the present disclosure contemplates robot arm **112** having any suitable tool attachment **140** for performing operations associated with the milking of a dairy cow **106**.

Returning to FIG. **1**, various components of system **100** (e.g., rotary encoder **116**, absolute encoder **124**, carriage actuator **132**, tool attachment **140**, and/or vision system **142**) may be communicatively coupled to controller **114** (e.g., via a network facilitating wireless or wireline communication). Controller **114** may control the position of robotic carriage **110** on track **108** (e.g., by controlling the extension/retraction of carriage actuator **132**) such that robot carriage **110** may track the movement of a stall **104** of rotary milking platform **102**. As a result, the robot arm **112** riding on robot carriage **110** may perform one or more functions associated with the milking of a dairy cow **106** located in the stall **104**. In addition, controller **114** may process image signals **146** generated by vision system **142** in order to position all or a portion of robot arm **112** relative to a dairy cow **106** in a milking stall **104** such that tool attachment **140** may perform one or more functions associated with the milking of the dairy cow **106**. Further, controller **114** may process image signals **146** generated by vision system **142** in order to determine whether to extend robot arm **112** between the hind legs of a dairy cow **106** based on whether a milking claw **107** is attached to the teats of the dairy cow **106**.

Controller **114** may include one or more computer systems at one or more locations. Each computer system may include any appropriate input devices (such as a keypad, touch screen, mouse, or other device that can accept information), output devices, mass storage media, or other suitable components for receiving, processing, storing, and communicating data. Both the input devices and output devices may include fixed or removable storage media such as a magnetic computer disk, CD-ROM, or other suitable media to both receive input from and provide output to a user. Each computer system may include a personal computer, workstation, network computer, kiosk, wireless data port, personal data assistant (PDA), one or more processors within these or other devices, or any other suitable processing device. In short, controller **114** may include any suitable combination of software, firmware, and hardware.

Controller **114** may additionally include one or more processing modules **148**. The processing modules **148** may each include one or more microprocessors, controllers, or any other suitable computing devices or resources and may work, either alone or with other components of system **100**, to provide a portion or all of the functionality of system **100** described herein. Controller **114** may additionally include (or be communicatively coupled to via wireless or wireline communication) one or more memory modules **150**. The memory modules **150** may each include any memory or database module and may take the form of volatile or non-volatile memory, including, without limitation, magnetic media, optical media, random access memory (RAM), read-only memory (ROM), removable media, or any other suitable local or remote memory component.

In certain embodiments, it may be desirable for robot carriage **110** to translate along track **108** at a speed corresponding to a milking stall **104** of rotary milking platform **102** such that the robot arm **112** riding on robot carriage may perform one or more functions associated with the milking of a dairy cow **106** in the milking stall **104** while the rotary milking platform **102** is in motion. Accordingly, controller **114** may include position control logic **152**, which may include any information, logic, and/or instructions stored and/or executed by controller **114** to control the movement

of robot carriage **110** on track **108** relative to a stall **104** of rotary milking platform **102**. For example, position control logic **152** may be operable to control the movement of robot carriage **110** on track **108** based on one or more rotary encoder signals **118** generated by rotary encoder **116**.

In certain embodiments, position control logic **152** may determine a desired linear position for robot carriage **110** ($X_{desired}$) based on a comparison of (1) a first rotary encoder signal **118** corresponding to a rotational position of rotary milking platform **102** at which a particular stall **104** is adjacent to a starting linear position of robot carriage **110** on track **108** (X_{start}), and (2) a second rotary encoder signal **118** corresponding to a current position of the particular stall **104** (a position at which the particular stall **104** is adjacent to position located between the starting linear position of robot carriage **110** on track **108** (X_{start}), and an ending linear position of robot carriage **110** on track **108** (X_{end})). For example, the first rotary encoder signal **118** may comprise a count of pulses generated by rotary encoder **116** at the time when the particular stall **104** triggers a proximity switch (or any other suitable sensor) indicating that the particular stall **104** has reached a position adjacent to a starting linear position of robot carriage **110** on track **108** (X_{start}), and the second rotary encoder signal **118** may comprise a current count of pulses generated by rotary encoder **116**. As a result, the difference between the second rotary encoder signal **118** and the first rotary encoder signal **118** may correspond to a distance traveled by the particular stall **104** through the area adjacent to track **108**.

Because the outside circumference of rotary milking platform **102** and the number of pulses generated by rotary encoder **116** per revolution of rotary milking platform **102** may each be known (e.g., 50 meters and 1000 pulses/revolution, respectively), the distance traveled by a milking stall **104** of rotary milking platform **102** per pulse of rotary encoder **116** may also be known (e.g., 50 meters/1000 pulses, or 0.05 meters per pulse). Therefore, the number of pulses generated by rotary encoder **116** between the first rotational position (i.e., the position at which the milking stall **104** is adjacent to X_{start}) and the second rotational position may correspond to the total distance traveled by the milking stall **104** after passing the position adjacent X_{start}. Because robot carriage **110** will need to move from X_{start} the same distance to track the movement of the milking stall **104**, the desired linear position for robot carriage **110** ($X_{desired}$) relative to the starting linear position of robot carriage **110** (X_{start}) may be determined as follows:

$$X_{desired} = \frac{EV_2 - EV_1}{A}$$

where:

$X_{desired}$=linear position of robot carriage **110** relative to X_{start};

EV_1=rotary encoder value (# of pulses) of first rotary encoder signal;

EV_2=rotary encoder value (# of pulses) of second rotary encoder signal; and

A=distance traveled by a milking stall **104** per pulse of rotary encoder **116** ((# of pulses per revolution of rotary milking platform **102**)/(outside circumference of rotary milking platform **102**))

Having determined the desired linear position of robot carriage **110** on track **108**, position control logic **152** may be further operable to generate a position signal **154** to be

communicated to carriage actuator **132** (and/or actuator drive mechanism **134**). The position signal **154** may cause extension/retraction of carriage actuator **132** such that robot carriage **108** is moved to the desired linear position ($X_{desired}$). By repeating the above-described calculation of the desired linear position of robot carriage **110** ($X_{desired}$) at regular intervals, position control logic **152** may cause robot carriage **108** to track the movement of the particular stall **104** of milking parlor **102** as the stall moves adjacent to track **108**. Moreover, when a next stall **104** reaches a position adjacent to the starting linear position of robot carriage **110** on track **108** (X_{start}) (e.g., triggering the above-described proximity switch), position control logic **152** may cause robot carriage **108** to track the movement of the next stall **104**. As a result, position control logic **152** may allow robot carriage **104** to track the movement of each stall **104** of rotary milking platform **104** as each stall moves through the area adjacent to track **108**.

In certain embodiments, position control logic **152** may be further operable to determine an error between the calculated desired linear position for robot carriage **110** ($X_{desired}$) and an actual linear position of robot carriage **110** (X_{actual}). Position control logic **152** may determine the actual linear position of robot carriage **110** (X_{actual}) relative to the starting linear position of robot carriage **110** (X_{start}) based on the number of pulses of an absolute encoder signal **126** generated by absolute encoder **124** (as absolute encoder **124** may generate a known number of pulses per meter of linear movement of carriage **110**). If the determined error exceeds a threshold value (e.g., 0.1 meters), position control logic **152** may cause the rotation of rotary milking platform **102** to stop (e.g., by communicating a stopping signal to a rotary drive motor of rotary milking platform **102**).

With robot carriage translating laterally along track **108** at a speed corresponding to that of a milking stall **104** of rotary milking platform **102** (as described above), at least a portion of robot arm **112** may be extended between the legs of a dairy cow **106** in milking stall **104** in order to perform one or more operations associated with the milking of the dairy cow **106**. In order to avoid contact between the robot arm **112** and the dairy cow **106**, it may be desirable to ensure that the legs of the dairy cow **106**, such as the hind legs, are spaced far enough apart to allow for the extension of at least a portion of robot arm **112** there between. Accordingly, controller **114** may additionally include vision control logic **156**, which may include any information, logic, and/or instructions stored and/or executed by controller **114** to determine, based on image signal(s) **146** generated by vision system **142**, whether the hind legs of a dairy cow **106** are spaced far enough apart to allow for a particular operation by robot arm **112**. In a particular embodiment, vision control logic **156** may determine whether the hind legs of a dairy cow **106** are spaced far enough apart by analyzing image signal **146** to find particular edges of the rear of the dairy cow **106**. The particular edges may be located by analyzing depth information of the visual data and to determine which portions represent the dairy cow **106** and which portions do not (as the transitions between those portions may represent the particular edges of the rear of the dairy cow **106**).

For example, vision control logic **156** may process an image signal **146** to determine the depth of the pixels in the x-dimension (as reflected by the coordinate system illustrated in FIG. **3**), which may represent a distance between camera **144** and a particular object (e.g., the dairy cow **106**, a portion of the milking stall **104**, etc.) presented in the image signal **146**. An example method of determining the depth of pixels may be by measuring the time of flight of a

light signal between camera **144** and a particular object captured in image signal **146** in the x-dimension. Vision control logic **156** may then compare the depth information of a cluster of pixels of image signal **146** to the depth information of another cluster of pixels within a portion of image signal **146**. Because a cluster of pixels relatively close to camera **144** may signify the dairy cow **106** and a cluster of pixels relatively far away from camera **144** may signify an object other than the dairy cow **106** (e.g., a portion of the milking stall **104** housing the dairy cow **106**), a portion of image signal **146** where pixels transition from relatively close to camera **144** to relatively far away from to camera **144** (or vice versa) may correspond to an edge location of the dairy cow **106**.

FIG. **4** illustrates an example image signal **146** that may be processed by vision control logic **156** in order to determine whether the hind legs of a dairy cow **106** are spaced far enough apart to allow for a particular operation by robot arm **112**. Vision control logic **156**, by comparing depth information of the visual data (as described above), may process the image signal **146** to determine hip locations **402**, outer hind locations **404**, and inner hind locations **406**. In particular, vision control logic **156** may begin to determine whether the hind legs of the diary cow **106** are spaced far enough apart by locating hip location **402a**. Vision control logic **156** may do this by comparing the depth locations of pixels of an upper outer area of image signal **146**, or any other area of image signal **146** likely to include the hip of the dairy cow **106**. Vision control logic **156** may determine that the cluster of pixels where depth location transitions from being relatively close to camera **144** to relatively far from camera **144** (or vice versa) represents a first edge corresponding to the hip of the dairy cow **106**. In certain embodiments, this location may correspond with hip location **402a**. Vision control logic **156** may then store the hip location **402a** in memory **150** or in any other suitable component of controller **114**.

After determining the hip location **402a** of dairy cow **106**, vision control logic **156** may attempt to locate the hind leg of the dairy cow **106**. For example, vision control logic **156** may analyze a portion of the image signal **146** below the determined hip location **402a** in the y-dimension (as reflected by the coordinate system illustrated in FIG. **3**) as that location may be likely to include outer hind location **404a**. By locating edges in pixel depth in that area of image signal **146** (in a substantially similar manner to that described above), vision control logic **156** may locate outer hind location **404a** (which may be stored in memory **150** or in any other suitable component of controller **114**). Having determined outer hind location **404a**, vision control logic **156** may begin to analyze portions of the image signal **146** to the right of the determined hip location **402a** in the z-dimension (as reflected by the coordinate system illustrated in FIG. **3**) as the next encountered edge in depth in that direction may correspond to inner hind location **406a** (which may be stored in memory **150** or in any other suitable component of controller **114**).

In certain embodiments, vision control logic **156**, having determined inner hind location **406a**, may analyze portions of image signal **146** above and below (in the y-dimension, as reflected by the coordinate system illustrated in FIG. **3**) the determined inner hind location **406a** to locate subsequent edges in depth. These additional edges in depth may represent an outline of the inner edge of the hind leg of the dairy cow **106**.

Having determined hip location **402a**, outer hind location **404a**, inner hind location **406a**, and the inner edge of the

hind leg of the dairy cow **106**, vision control logic **156** may process the opposing side of image signal **146** to determine hip location **402***b*, outer hind location **404***b*, inner hind location **406***b*, and the inner edge of the other hind leg of the dairy cow **106** (in a substantially similar manner to that described above).

Once the inner edges of each hind leg of the dairy cow **106** have been located, vision control logic **156** may determine whether the hind legs of the dairy cow **106** are far apart enough to allow for the proper operation of at least a portion of robot arm **112** by calculating the distance between the hind legs. For example, vision control logic **156** may calculate the distance between inner hind locations **406***a* and **406***b*. As another example, vision control logic **156** may determine an inner-most point along the inner edge of each hind leg of the dairy cow **106** (e.g., the location along each determined inner edge closest to the center of the image signal **146**) and calculate the distance between those two points. In certain embodiments, the inner-most point of each hind leg may be calculated within a working area. For example, the working area may be an area between the inner hind edges where robot arm **112** may operate. The measurements of the working area may be based at least in part upon the width and/or height of a portion of robot arm **112** likely to be operating between the hind legs of the dairy cow **106**. In such an embodiment, vision control logic **156** may analyze visual data along the detected inner hind edge in a substantially vertical direction within the working area to determine the inner-most location. If the determined distance between the hind legs exceeds a distance threshold (e.g., a minimum distance allowing for the robot arm **112** to properly operate), vision control logic **156** may determine that the hind legs of the dairy cow **106** are spaced far enough apart to allow for the proper operation of at least a portion of robot arm **112**.

If vision control logic **156** determines that the hind legs of the dairy cow **106** are spaced far enough apart, vision control logic **156** may facilitate the communication of signals to one or more of arm actuators **138**, the communicated signals causing extension/retraction of arm actuators **138** such that at least a portion of robot arm **112** (e.g., tool attachment **140**) extends toward the space between the hind legs of the dairy cow **106** (e.g., at a predetermined height relative to the milking stall in which the dairy cow **106** is located). Because image signal **146** may comprise a three-dimensional video image (as described above), the image signal **146** may change in real time as camera **144** moves toward the dairy cow **106**. Accordingly, the present disclosure contemplates that vision control logic **156** may update, either continuously or at predetermined intervals, the determined leg positions as image signal **146** changes. Furthermore, vision control logic **156**, or any other suitable component, may be operable to determine whether a portion of robot arm **112** is in contact with the dairy cow **106**. In such an instance, vision control logic **156** may facilitate the communication of signals to one or more of arm actuators **138** to cause extension/retraction of arm actuators **138** such that at least a portion of robot arm **112** is no longer in contact with the dairy cow.

Although the above-described example embodiment relates to determining whether there is enough space between the hind legs of a dairy cow **106**, the present disclosure contemplates that vision control logic **156** performance may determine, in a similar manner, whether there is enough space between a front leg and a hind leg of a dairy cow **106**.

Prior to extending at least a portion of the robot arm **112** between the hind legs of the dairy cow **106** to perform certain functions associated with the milking of the dairy cow **106** (e.g., applying disinfectant to the teats to the dairy livestock **106**), it may be desirable to ensure that a milking claw **107** is not attached to the teats of a diary cow **106**. Accordingly, controller **114** may additionally include milking claw detection logic **158**, which may include any information, logic, and/or instructions stored and/or executed by controller **114** to determine whether to extend robot arm **112** between the hind legs of a dairy cow **106** based on whether a milking claw **107** is attached to the teats of the dairy cow **106**.

In certain embodiments, milking claw detection logic **158** may determine whether a milking claw **107** is attached to the teats of the dairy cow **106** when a milking stall **104** in which the dairy cow **106** is located enters an area adjacent to track **108** and robot arm **112**. For example, milking claw detection logic **158** may receive a trigger (e.g. from a proximity switch or any other suitable sensor associated with the rotary milking platform **102**) indicating that the milking stall **104** in which the dairy cow **106** is located has entered an area adjacent to track **108**, and may determine whether a milking claw **107** is attached in response to that trigger. Moreover, milking claw detection logic **158** may determine whether a milking claw **107** is attached while rotary milking platform **102** is rotating and while the robot carriage **110** carrying robot arm **112** translates along track **108** at a speed corresponding to that of the stall **104** housing the dairy cow **106** (as described above) Alternatively, milking claw detection logic **158** may determine whether a milking claw **107** is attached while robot arm **112** remains stationary, and robot carriage **110** may begin to track the movement of the milking stall subsequent to a determination that the milking claw **107** is not attached.

Milking claw detection logic **158** may determine whether a milking claw **107** is attached using one of at least three different methods. As a first method, milking claw detection logic **158** may access a milking claw detachment signal **147**, the milking claw detachment signal **147** indicating whether the milking claw **107** has detached from the teats of the dairy cow. Milking claw detachment signal **147** may be generated by a computer system associated with the rotary milking platform **102**. Alternatively, rather than indicating whether the milking claw **107** has detached, milking claw detachment signal **147** may indicate whether the milking claw **107** is attached to the teats of the dairy cow **106**. In other embodiments, milking claw detachment signal **147** may indicate other operational data associated with the rotary milking platform **102** from which milking claw detection logic **158** may determine whether milking claw **107** is attached. For example, milking claw detachment signal **147** may indicate whether vacuum pressure is being applied to the milking claw **107** as part of a milking operation, from which milking claw detection logic **158** may determine that milking claw **107** is attached to the teats of the dairy cow. Thus, milking claw detection logic **158** may determine whether the milking claw **107** is attached based on milking claw detachment signal **147**.

As a second method of determining whether milking claw **107** is attached, milking claw detection logic **158** may determine whether the milking claw **107** is present at a storage location **115** (i.e. no longer attached to the teats of the dairy cow) by processing an image signal **146** (e.g., a three-dimensional video image signal), as described above) representing the storage location **115** of a milking stall **104**. FIGS. **5A-5B** illustrate example snapshots **500***a-b* of an image signal **146** corresponding to an example storage location **115** of an example milking stall **104**, according to

certain embodiments of the present disclosure. In particular, FIG. 5A illustrates an example snapshot 500*a* of an image signal 146 corresponding to storage location 115 when milking claw 107 is present at storage location 115, and FIG. 5B illustrates an example snapshot 500*b* of an image signal 146 corresponding to storage location 115 when milking claw 107 is not present at storage location 115.

As one way of determining whether the milking claw 107 is present at the storage location 115 based on an accessed image signal 146, milking claw detection logic 158 may compare the accessed image signal 146 to a reference image signal 160. In certain embodiments, the reference image signal 160 may correspond to storage location 115 when the milking claw 107 is present at storage location 115 (e.g., snapshot 500*a* of FIG. 5A). The comparison may be performed by comparison of individual depth values of image signal 146 with individual depth values of the reference image signal 160, by correlation of image signal 146 with the reference image signal 160 using any suitable correlation detector, or by any other suitable method. If image signal 146 is sufficiently similar to the reference image signal 160, milking claw detection logic 158 may determine that milking claw 107 is present at storage location 115, and therefore that milking claw 107 is not attached to the teats of the dairy cow. In certain other embodiments, the reference image signal 160 may correspond to storage location 115 when the milking claw 107 is not present at storage location 115 (e.g., snapshot 500*b* of FIG. 5B). In that case, if image signal 146 is sufficiently similar to the reference image signal 160, milking claw detection logic 158 may determine that milking claw 107 is not present at storage location 115, and therefore that milking claw 107 is attached to the teats of the dairy cow.

Alternatively, milking claw detection logic 158 may compare an accessed image signal 146 to two reference image signals 160: a first reference image signal 160 that corresponds to storage location 115 when the milking claw 107 is present at storage location 115, and a second reference image signal 160 that corresponds to storage location 115 when the milking claw 107 is not present at storage location 115. Milking claw detection logic 158 may then determine whether image signal 146 is more similar to the first reference image signal 160, in which case milking claw detection logic 158 may determine that milking claw 107 is not attached to the teats of the dairy cow, or to the second reference image signal 146, in which case milking claw detection logic 158 may determine that milking claw 107 is attached to the teats of the dairy cow.

As another way of determining whether the milking claw 107 is present at the storage location 115 based on an accessed image signal 146, milking claw detection logic 158 may compare the plurality of depth values of image signal 146 to a threshold depth value. Because milking claw 107, when present at storage location 115, may be relatively close to camera 144 as compared to the space located around milking claw 107, and as compared to storage location 115 when milking claw 107 is not present, if many depth values in image signal 146 are smaller (i.e. closer to camera 144) than a threshold depth value, it may indicate that milking claw 107 is present at storage location 115. Conversely, if few depth values in image signal 146 are smaller than a threshold depth value, it may indicate that milking claw 107 is not present at storage location 115. In certain embodiments, milking claw detection logic 158 may count the number of depth values in image signal 146 that are smaller than the threshold depth value. If the counted number is greater than a determined triggering count, milking claw

detection logic 158 may determine that milking claw 107 is present at storage location 115, and therefore that milking claw 107 is not attached to the teats of the dairy cow. Otherwise, milking claw detection logic 158 may determine that milking claw 107 is not present at storage location 115, and therefore that milking claw 107 is attached to the teats of the dairy cow. The determined triggering count may be set to one, an arbitrary number, a number based on the resolution of camera 144, a number determined by analyzing one or more reference image signals 160, or any other suitable number.

In alternative embodiments, milking claw detection logic 158 may count the number of depth values in image signal 146 that exceed the threshold depth value. If the counted number is greater than a determined triggering count, milking claw detection logic 158 may determine that milking claw 107 is not present at storage location 115, and therefore that milking claw 107 is attached to the teats of the dairy cow. Otherwise, milking claw detection logic 158 may determine that milking claw 107 is present at storage location 115, and therefore that milking claw 107 is not attached to the teats of the dairy cow.

In some embodiments, the threshold depth value may be selected based on the distance between camera 144 and storage location 115. In other embodiments, the threshold depth value may be selected based on a reference image signal 160. For example, using a reference image signal 160 corresponding to storage location 115 when the milking claw 107 is not present at storage location 115, as illustrated in FIG. 5B, the threshold value could be set such that all or substantially all of the depth values in the reference image signal 160 would be greater than the threshold value.

As a third method of determining whether milking claw 107 is attached, milking claw detection logic 158 may process an image signal 146 (e.g., a three-dimensional video image signal) representing the rear of the dairy cow 106 in order to determine whether the milking claw 107 is attached to the teats of the dairy cow 106. For example, milking claw detection logic 158 may determine whether milking claw 107 is attached by processing the image signal 146 of the rear of the dairy cow 106 using either of the techniques described above—comparing image signal 146 to a reference image signal 160, or comparing the plurality of depth values in image signal 146 to a threshold depth value—or any other suitable technique. In this case, reference image signal 160 may correspond to the rear of the dairy cow when milking claw 107 is attached (i.e. present in the image). Similarity of image signal 146 to reference image signal 160 may then indicate that milking claw 107 is attached. Conversely, reference image signal 160 may correspond to the rear of the dairy cow when milking claw 107 is not attached, in which case similarity to image signal 146 may indicate that milking claw 107 is not attached. Likewise, the threshold depth value may be set based on one or more reference image signals 160 or based on a distance between camera 144 and the expected location of milking claw 107 when attached (e.g. the teats of the cow).

Because camera 144 of vision system 142 may not generate both of the above-described image signals 146 (i.e., the image signal 146 including storage location 115 and the image signal 146 including the rear of the dairy cow 106) with robot arm 112 in the same position (as both locations may not be in the field of view of camera 144), all or a portion of robot arm 112 may be able to articulate between the different imaging positions. For example, as illustrated in FIGS. 6A-6B, robot arm 112 may be operable to pivot between an imaging position (e.g., a position where an

image signal **146** representing storage location **115** may be generated, as illustrated in FIG. **6A**) and an operating position (e.g., a position where an image signal **146** representing the rear of the dairy cow **106** may be generated, as illustrated in FIG. **6A**). This illustrated articulation of robot arm **112** be accomplished, for example, by rotation of tool attachment **140** about the point of attachment to arm member **136** (e.g. by extension/retraction of arm actuator **138**). In certain embodiments (e.g., embodiments in which the attachment of a milking claw is determined by processing an image signal **146** representing the storage location **115**, as described above), milking claw detection logic **158** may control the robot arm **112** to pivot to the imaging position (e.g. by communicating a signal to arm actuator **138** to extend or retract) before accessing the image signal **146** upon which the determination is made. Subsequently, after determining that a milking claw **107** is attached, controller **114** may control the robot arm **112** to pivot to the operating position (e.g. by communicating a signal to arm actuator **138** to extend or retract) before accessing the image signal **146** to determine the position of the cow's legs (e.g. using vision control logic **156**).

If, based on one or more of the above-described method, milking claw detection logic **158** determines that a milking claw **107** is not attached, controller **114** may initiate performing further desired operations (e.g. the disinfectant application process) by extending robot arm **112** between the hind legs of dairy cow **106** (e.g. using vision control logic **156**). Otherwise, no further action may be performed until a next milking stall **104** enters the area adjacent to track **108** and robot arm **112**.

Particular embodiments of system **100** may provide one or more technical advantages. For example, certain embodiments of system **100** may allow robot carriage **110** to accurately track the movement of a stall **104** of the adjacent rotary milking platform **102**. Because the robot carriage **110** may carry a robot arm **112** configured to perform one or more functions associated with the milking of a dairy cow **106** located in the stall **104** of the rotary milking platform **102** (e.g., a robotic arm for applying disinfectant to the teats of the dairy livestock and/or attaching a milking claw to the teats of the dairy livestock), certain embodiments of system **100** may facilitate a reduction in the need for human labor to perform certain functions associated with milking dairy cows **106** using rotary milking platform **102**. As a result, certain embodiments of system **100** may reduce the cost associated with certain dairy milking operations. In addition, the automation facilitated by certain embodiments of system **100** may increase the throughput of rotary milking platform **102**, thereby increasing the overall milk production of rotary milking platform **102**.

As another example, using vision system **142** may improve the visibility of the dairy cow **106** and may facilitate milking-related operations from a position to the rear of the dairy cow **106**. Approaching from the rear of the dairy cow makes it less likely that the cow will be distracted by the milking equipment. Furthermore, approaching from the rear of the dairy cow makes it less likely that the dairy livestock will kick the milking equipment, vision system **142**, or any other component of the system of the present disclosure. Additionally, use of vision system **142** may allow for the safe operation of robot arm **112** without disturbing the dairy cow during any portion of the milking operation. For example, vision system **142** may facilitate the detection of a properly spaced working area between the hind legs of the dairy cow, allowing robot arm **112** to extend between the dairy cow's hind legs without coming into contact with the

dairy cow. Moreover, by preventing the robot arm **112** from extending between the legs of a dairy cow **106** while a milking claw is attached to the teats of the cow, certain embodiments of system **100** may prevent injury to the cow and/or damage to the robot arm **112** or other components of system **100**.

Although a particular implementation of system **100** is illustrated and primarily described, the present disclosure contemplates any suitable implementation of system **100**, according to particular needs. For example, although certain of the above-described functions are described as being performed by position control logic **152**, vision control logic **156**, or milking claw detection logic **158**, the present disclosure contemplates the described functionality as being performed by any suitable logic or combination of logic, according to particular needs. Additionally, although the vision system **142** housing camera **144** is depicted and described above as being positioned on tool attachment **140**, the present disclosure contemplates vision system **142** being located separate from tool attachment **140**, as depicted in the alternative example rotary milking system **700** depicted in FIG. **7**. In the depicted alternative system **700** embodiments, a standalone vision system **702** housing a camera **704** may be positioned on the ground near robot arm **112**. Use of standalone vision system **702** may be advantageous when a storage location **115** of a milking stall **104** would be below the line of sight of a camera mounted on robot arm **112**.

FIG. **8** illustrates an example method **800** for controlling the position of robot carriage **110** based on the position of a stall **104** of an adjacent rotary milking platform **102**, according to certain embodiments of the present disclosure. Although method **800** is described with regard to tracking the movement of a single stall **104**, the present disclosure contemplates that method **800** could be performed for each stall **104** of a rotary milking platform **102**.

The method begins at step **802**. At step **804**, controller **114** receives a first rotary encoder signal **118** generated by rotary encoder **116**. The first rotary encoder signal **118** may comprise a number of pulses generated by rotary encoder **116** when a particular milking stall **104** of rotary milking platform **102** is located adjacent to the starting linear position of robot carriage **110** on the track **108** positioned adjacent to rotary milking platform **102**. At step **806**, controller **114** receives a second rotary encoder signal **118** indicating a second rotational position of the particular stall **104** of rotary milking platform **102**.

At step **808**, controller **114** determines a desired linear position of robot carriage **110** on track **108** based on the difference between the second rotary encoder signal **118** and the first rotary encoder signal **118** (as described above with regard to FIG. **1**). The determined desired linear position of robot carriage **110** is a position corresponding to the second rotational position of the particular stall **104** (i.e., the current position of the particular stall **104**).

At step **810**, controller **114** communicates a position signal **154** to a carriage actuator **132** coupled to robot carriage **110** and track **108**. The position signal **154** may cause extension/retraction of carriage actuator **132** such that robot carriage **110** is moved along track **108** to the desired linear position.

At step **812**, controller **114** receives an absolute encoder signal **126** generated by absolute encoder **124**. The absolute encoder signal **126** corresponds to the actual linear position of robot carriage **110** on track **108** (as absolute encoder **124** may generate a known number of pulses per meter traveled by robot carriage **110**). At step **814**, controller **114** determines a position error based on a comparison of the actual

linear position of the robot carriage **110** and the previously-calculated desired linear position of robot carriage **110**. At step **816**, controller **114** determines if the position error exceeds a threshold value. If the position error does exceed the threshold value, controller **114** causes the rotation of rotary milking platform **102** to stop (e.g., by communicating a stopping signal to a rotary drive motor of rotary milking platform **102**) and the method ends at step **818**. Otherwise, the method returns to step **804**.

Although the steps of method **800** have been described as being performed in a particular order, the present disclosure contemplates that the steps of method **800** may be performed in any suitable order, according to particular needs.

Although the present disclosure has been described with several embodiments, diverse changes, substitutions, variations, alterations, and modifications may be suggested to one skilled in the art, and it is intended that the disclosure encompass all such changes, substitutions, variations, alterations, and modifications as fall within the spirit and scope of the appended claims.

FIG. **9** illustrates an example method for analyzing an image signal **146** to determine if the hind legs of a dairy cow **106** are spaced far enough apart to allow for extension of robot arm **112**, according to certain embodiments of the present disclosure. The example method may begin at step **900**. At step **900**, vision control logic **156** may begin to compare pixels of an upper outer area of an image. For example, vision control logic **156** may access image signal **146** generated by camera **144**. Vision control logic **156** may compare the pixels of image signal **146** by determining the depth of the pixels. In certain embodiments, the depth may be determined by measuring the time of flight of a light signal between camera **144** and a particular object captured in image signal **146**. After collecting the depth information of a particular portion of pixels, the method may proceed to step **904**. At step **904**, vision control logic **156** may determine whether some pixels are closer than other pixels within a portion of image signal **146**. For example, vision control logic **156** may compare the depth information of a group of pixels to determine if some pixels are closer than other pixels. A portion of image signal **146** which transitions from a cluster of pixels further from camera **144** to a cluster of pixels closer to camera **144** (or vice versa) may signify that an edge of the dairy cow **106** has been found. The cluster of pixels with depth information further away from camera **144** may signify that the image data is of an object other than an edge of the dairy cow **106**. If vision control logic **156** has determined that some pixels are not closer than other pixels, then the example method may return to step **900** and continue analyzing information captured by camera **144**. Otherwise, the example method may proceed to step **908**.

At step **908**, vision control logic **156** may associate the location of the cluster of pixels that are closer to camera **144** with an edge of the dairy cow **106**. For example, vision control logic **156** may have determined that the cluster of pixels represents a first edge corresponding to the hip of the dairy cow **106**. In certain embodiments, this location may correspond with hip location **402***a* of FIG. **4**. Visual control logic **156** may store this association in memory **150** or in any other suitable component of controller **114**.

After finding the hip of the dairy cow **106**, vision control logic **156** may attempt to locate the hind leg of the dairy cow **106**. To do this, at step **912**, vision control logic **156** may compare the depth information of pixels in a lower outer area of image signal **146** or any other portion of image signal **146** that may include the hind legs of the dairy cow **106**. For example, vision control logic **156** may traverse pixels of

image signal **146** in a downward direction trying to locate the outer edge of a hind leg of a dairy cow **106**.

Vision control logic **156** may then determine the location of an outer edge of a hind leg at step **916**. Vision control logic **156** may do this by determining whether some pixels are closer than other pixels. A portion of image signal **146** which transitions from a cluster of pixels further from camera **144** to a cluster of pixels closer to camera **144** (or vice versa) may signify that an edge of the dairy cow **106** has been found. If vision control logic **156** has determined that some pixels are not closer than other pixels, then the example method may return to step **912** and continue analyzing information captured by camera **144**. Otherwise, the example method may proceed to step **920**.

At step **920**, vision control logic **156** may associate the location of the cluster of pixels that are closer to camera **144** than another cluster of pixels within a portion of visual signal **146** with an edge of the dairy cow **106**. For example, vision control logic **156** may have determined that the cluster of pixels represents an edge corresponding to an outer edge of a hind leg of the dairy cow **106**. In certain embodiments, this location may correspond with outer edge location **404***a* of FIG. **4**. Vision control logic **156** may store this association in memory **150** or in any other suitable component of controller **114**.

Vision control logic **156** may then attempt to determine an inner edge location of a hind leg. At step **924**, vision control logic **156** may begin to scan the depth information of pixels along a lower inner area of image signal **146**. For example, vision control logic **156** may traverse pixels along the z-dimension (as illustrated in FIG. **3**) from outer edge location **404***a* to the center of image signal **146** trying to locate an inner edge of the hind leg of the dairy cow **106**. At step, **928**, vision control logic **156** may determine whether some pixels are closer than other pixels. For example, vision control logic **156** may compare the depth information of a group of pixels to determine if a cluster of the pixels are closer than another cluster of pixels. If vision control logic **156** has determined that some pixels are not closer than other pixels, then the example method may return to step **924** and continue analyzing information captured by camera **144**. Otherwise, the example method may proceed to step **932**.

At step **932**, vision control logic **156** may associate the location of the cluster of pixels that are closer to camera **144** with an edge of the dairy cow **106**. For example, vision control logic **156** may have determined that the cluster of pixels represents an edge corresponding to an inner edge of a hind leg of the dairy cow **106**. In certain embodiments, this location may correspond with inner edge location **406***a* of FIG. **4**. In certain embodiments, vision control logic **156** may determine edge location **406***a* is the inner-most location of the hind legs of the dairy cow. For example, vision control logic **156** may analyze visual data along the detected inner edge in a substantially vertical direction to determine the inner-most location of the hind leg. The portion of the hind leg closest to the center of the dairy cow in the z-dimension may be considered the inner-most portion. In other embodiments, vision control logic **156** may determine edge location **406***a* is the inner-most location of the hind legs within the working area of dairy cow **106**. For example, the working area may be an area between the inner hind edges where robot arm **112** may operate. The measurements of the working area may be based at least in part upon the width and/or height of a portion of robot arm **112** likely to be operating between the hind legs of the dairy cow **106**. In such an embodiment, vision control logic **156** may analyze visual data along the detected inner hind edge in a substan-

tially vertical direction within the working area to determine the inner-most location. Vision control logic **156** may store the association between the determined location and inner edge location **406a** in memory **150** or in any other suitable component of controller **114**.

After finding the edges corresponding to a side of the dairy cow **106**, vision control logic **156** may determine if data points from both sides of the dairy cow **106** have been collected at step **936**. If vision control logic **156** determines that data points from only a single side of the dairy cow **106** has been found, vision control logic **156** may proceed to determine the locations of the other hind leg of the dairy cow **106** at step **900**. Otherwise, the example method may proceed to step **940**.

Once edges of the dairy cow **106** are located, at step **940**, vision control logic **156** may determine whether the hind legs of the dairy cow **106** are far apart enough to allow for the proper operation of at least a portion of robot arm **112**. For example, after detecting the hind legs of the dairy cow, vision control logic **156** may calculate the distance between the hind legs. Vision control logic **156** may use any portion of image signal **146** to calculate the distance between the hind legs. In certain embodiments, vision control logic **156** may calculate the distance between the two inner hind edges of the dairy cow **106**. As an example, vision control logic **156** may calculate the distance between inner edge locations **406a** and **406b** of FIG. **4**. Vision control logic **156** may then determine whether the hind legs are far enough apart to properly operate at least a portion of robot arm **112**. In certain embodiments, there may be a distance threshold associated with robot arm **112**, wherein the distance threshold specifies a minimum distance between a diary cow's hind legs which allows for the robot arm **112** to properly operate. For example, there may be a distance threshold based at least in part on the width of robot arm **112** and/or any other equipment robot arm **112** may utilize to perform a particular function. If vision control logic **156** determines that the hind legs of the dairy cow **106** are far enough apart, vision control logic **156** may proceed with allowing robot arm **112** to operate between the hind legs of the dairy cow **106** at step **944**. Otherwise, vision control logic **156** may not facilitate the instruction of robot arm **112** to proceed with a particular operation between the hind legs of the dairy cow and the example method may end.

At step **944**, vision control logic **156**, having determined the positions of each of the hind legs of the dairy cow, may facilitate the communication of signals to one or more of arm actuators **138**, the communicated signals causing extension/retraction of arm actuators **138** such that at least a portion of robot arm **112** (e.g., tool attachment **140**) extends toward the space between the hind legs of the dairy cow (e.g., at a predetermined height relative to the milking stall in which the dairy cow is located).

Although the steps of method **900** have been described as being performed in a particular order, the present disclosure contemplates that the steps of method **1000** may be performed in any suitable order, according to particular needs.

FIG. **10** illustrates an example method **1000** for determining whether to operate a robot in conjunction with a rotary milking platform based on detection of a milking claw **107**, according to certain embodiments of the present disclosure. The method begins at step **1002**. At step **1004**, controller **114** waits for a trigger indicating that a stall in which a dairy cow is located (e.g., a stall **104** of a rotary milking platform **102** positioned adjacent to track **108** and robot arm **112**, as illustrated in FIG. **1**) has entered an area adjacent to robot arm **112**. For example, the trigger may be

received from a proximity switch or any other suitable sensor associated with the rotary milking platform. If controller **114** receives the trigger, the method proceeds to step **1006**. If not, controller **114** returns to step **1004** and continues to wait for the trigger.

At step **1006**, controller **114** determines whether a milking claw is attached (e.g. milking claw **107**, as described in connection with FIG. **1**). This determination may be made using any of the three methods described above (e.g. using milking claw detection logic **158**, as described in connection with FIG. **1**), or in any other suitable way. In some embodiments, robot arm **112** may translate laterally to keep pace with the rotation of rotary milking platform **102** while making this determination (e.g. using position control logic **152**, as described in connection with FIG. **1**). If controller **114** determines that a milking claw is attached, the method proceeds to step **1008**, where the controller **114** allows the milking stall to rotate by without extending the robotic arm between the legs of the dairy cow. If controller **114** determines that a milking claw is not attached, the method proceeds to step **1010**.

At step **1010**, controller **114** determines whether the hind legs of the dairy cow are far apart enough to allow for the proper operation of at least a portion of the robot arm. If it is not already doing so, the robot arm begins to track the rotational movement of the milking stall by moving laterally along a track (e.g. using position control logic **152**). As a result, the robot arm may keep pace with a dairy cow located in a milking stall of the rotary milking platform. The positions of the hind legs of the dairy cow and the distance between them may be determined by processing an image signal from a camera (e.g. image signal **146** generated by vision system **142** housing camera **144**, as described in connection with FIG. **2**) in the manner described above (e.g. using vision control logic **156**). If the hind legs are far enough apart (e.g. as determined by vision control logic **156**), the method proceeds to step **1012**. If not, the method proceeds to step **1008**, where the controller **114** allows the milking stall to rotate by without extending the robotic arm between the legs of the dairy cow. In some embodiments, the robot arm may then stop tracking the movement of the stall in order to allow the stall to rotate by.

At step **1012**, controller **114**, having determined the positions of each of the hind legs of the dairy cow, may communicate signals to one or more of arm actuators **138**, the communicated signals causing extension/retraction of arm actuators **138** such that at least a portion of robot arm **112** (e.g., tool attachment **140**) extends toward the space between the hind legs of the dairy cow (e.g., at a predetermined height relative to the milking stall in which the dairy cow is located).

At step **1014**, controller **114** may control the robot arm to perform the desired operation using the tool attachment. For example, a spray tool attachment may initiate the discharge of a disinfectant to the teats of the dairy cow. Once the function has been performed, controller **114** may, at step **1016**, communicate signals to one or more of arm actuators **138**, such that the robot arm retracts from between the legs of the dairy cow. In some embodiments, the robot arm may then stop tracking the movement of the stall in order to allow the stall to rotate by. The method then either returns to step **1004** (if there are additional dairy cows on which milking operations are to be performed) or ends at step **1018** (if there are no additional dairy cows on which milking operations are to be performed).

Although the steps of method **1000** have been described as being performed in a particular order, the present disclo-

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sure contemplates that the steps of method **1000** may be performed in any suitable order, according to particular needs.

Although the present disclosure has been described with several embodiments, diverse changes, substitutions, variations, alterations, and modifications may be suggested to one skilled in the art, and it is intended that the disclosure encompass all such changes, substitutions, variations, alterations, and modifications as fall within the spirit and scope of the appended claims.

What is claimed is:

1. A system for controlling the position of a robot carriage, comprising:

a linear carriage track positioned adjacent to a rotary milking platform;

a robot carriage positioned on the carriage track such that the robot carriage may move along the carriage track; and

a controller that:

determines a movement of a milking stall of the rotary milking platform from a first rotational position to a second rotational position;

determines a position of the robot carriage on the carriage track corresponding to the movement of the milking stall of the rotary milking platform; and

communicates a position signal to a carriage actuator coupled to the robot carriage and the carriage track, the position signal causing the carriage actuator to move the robot carriage along the carriage track to the determined position in conjunction with the movement of the rotary milking platform.

2. The system of claim **1**, wherein the robot carriage comprises a robot arm having a spray tool operable to discharge an amount of disinfectant to the teats of a dairy livestock located in the milking stall of the milking platform as the rotary milking platform rotates.

3. The system of claim **1**, wherein the robot carriage comprises a robot arm having a preparation tool operable to prepare the teats of a dairy livestock located in the milking stall of the milking platform for the attachment of one or more teat cups of a milking claw as the rotary milking platform rotates.

4. The system of claim **1**, wherein the robot carriage comprises a robot arm having a teat cup attachment tool that attaches one or more teat cups of a milking claw to the teats of a dairy livestock located in the milking stall of the milking platform as the rotary milking platform rotates.

5. The system of claim **1**, wherein the robot carriage comprises a robot arm operable to extend between the legs of a dairy livestock located in the milking stall as the rotary milking platform rotates.

6. The system of claim **1**, wherein:

the robot carriage moves from a first position to a second position;

the first position of the robot carriage is a first linear position on the carriage track; and

the second position of the robot carriage is a second linear position on the carriage track.

7. The system of claim **1**, wherein the controller uses a plurality of rotary encoder signals to determine the first and second rotational positions of the milking stall.

8. A method for controlling the position of a robot carriage, comprising:

determining by a controller a movement of a milking stall of a rotary milking platform from a first rotational position to a second rotational position;

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determining by the controller a position of the robot carriage on a linear carriage track corresponding to the movement of the milking stall of the rotary milking platform; and

moving the robot carriage along the carriage track to the determined position in conjunction with the movement of the rotary milking platform.

9. The method of claim **8**, wherein the robot carriage comprises a robot arm having a spray tool operable to discharge an amount of disinfectant to the teats of a dairy livestock located in the milking stall of the milking platform as the rotary milking platform rotates.

10. The method of claim **8**, wherein the robot carriage comprises a robot arm having a preparation tool operable to prepare the teats of a dairy livestock located in the milking stall of the milking platform for the attachment of one or more teat cups of a milking claw as the rotary milking platform rotates.

11. The method of claim **8**, wherein the robot carriage comprises a robot arm having a teat cup attachment tool operable to attach one or more teat cups of a milking claw to the teats of a dairy livestock located in the milking stall of the milking platform as the rotary milking platform rotates.

12. The method of claim **8**, wherein the robot carriage comprises a robot arm operable to extend between the legs of a dairy livestock located in the milking stall as the rotary milking platform rotates.

13. The method of claim **8**, wherein:

the robot carriage moves from a first position to a second position;

the first position of the robot carriage is a first linear position on the carriage track; and

the second position of the robot carriage is a second linear position on the carriage track.

14. The method of claim **8**, further comprising using a plurality of rotary encoder signals to determine the first and second rotational positions of the milking stall.

15. A system for controlling the position of a robot carriage, comprising:

a carriage track positioned adjacent to a rotary milking platform;

a robot carriage positioned on the carriage track; and

a controller that causes the robot carriage to move linearly along the carriage track in conjunction with a rotational movement of the rotary milking platform;

wherein the controller uses a plurality of rotary encoder signals to determine the rotational movement of the milking stall.

16. The system of claim **15**, wherein the robot carriage comprises a robot arm having a spray tool operable to discharge an amount of disinfectant to the teats of a dairy livestock located in the milking stall of the milking platform as the rotary milking platform rotates.

17. The system of claim **15**, wherein the robot carriage comprises a robot arm having a preparation tool operable to prepare the teats of a dairy livestock located in the milking stall of the milking platform for the attachment of one or more teat cups of a milking claw as the rotary milking platform rotates.

18. The system of claim **15**, wherein the robot carriage comprises a robot arm having a teat cup attachment tool that attaches one or more teat cups of a milking claw to the teats of a dairy livestock located in the milking stall of the milking platform as the rotary milking platform rotates.

19. The system of claim **15**, wherein the robot carriage comprises a robot arm operable to extend between the legs of a dairy livestock located in the milking stall as the rotary milking platform rotates.

20. The system of claim **15**, wherein the rotational movement of the rotary milking platform is between a first rotational position and a second rotational position.

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